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Abundance and Age-Sex-Size Composition of Chum Salmon Escapements in the Chena and Salcha Rivers, 1992

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ABSTRACT

Abundance of chum salmon *Oncorhynchus keta* that returned to spawn in the Chena and Salcha rivers during 1992 was estimated in August using mark-recapture techniques. A boat-mounted electrofishing unit equipped with pulsed-direct current was used to capture chum salmon during the marking events. Carcasses of chum salmon were collected and examined for marks during the recapture events. Estimated abundance of chum salmon in the Chena River was 6,083 fish (SE = 1,857 fish), with 3,359 females (SE = 1,034 fish) and 2,724 males (SE = 842 fish). Estimated abundance of chum salmon in the Salcha River was 14,057 fish (SE = 3,813 fish), with 7,945 females (SE = 2,167 fish) and 6,112 males (SE = 1,674 fish). Age and size composition estimates from both rivers indicate that age 0.4 fish (1987 brood year) predominated. Precision in estimates of abundance in both rivers was compromised by bias due to unequal recapture rates between sections of river.

KEY WORDS: chum salmon, *Oncorhynchus keta*, Chena River, Salcha River, abundance, age-sex-size compositions.

INTRODUCTION

Although mark-recapture techniques for estimation of escapements of chinook salmon *Oncorhynchus tshawytscha* in the Chena and Salcha rivers are well developed (Skaugstad 1990 and Evenson 1991, 1992), escapement of summer-run chum salmon *Oncorhynchus keta* in these rivers continues to be periodically indexed with aerial survey techniques. To assess the feasibility of using mark-recapture techniques for estimating escapements of chum salmon, mark-recapture experiments were performed in the Chena and Salcha rivers during August of 1992.

Specific objectives of the feasibility study were to estimate:

1. the abundance of adult chum salmon in the Chena and Salcha rivers; and,

2. the age, sex, and size compositions of chum salmon in the Chena and Salcha rivers.

Since the same techniques have been used for chinook salmon and the average coefficient of variation (CV) of abundance estimates has been 16.8% for the Salcha River (1987-1992, Skaugstad *In prep*) and 12.2% for the Chena River (1986-1992, Evenson *In prep*), a CV of approximately 15% would indicate the mark-recapture is a feasible method for enumerating chum salmon in these rivers.

METHODS

Capture and Marking

In both rivers, chum salmon were captured with a boat-mounted electrofishing system utilizing pulsed-direct current (Clark 1985). Chum salmon that were stunned in the electrical field were dip netted and placed in an aerated holding tub. All captured chum salmon were measured from mid-eye to fork-of-tail (ME-FK) to the nearest 5 mm, sexed, tagged, a combination of fins clipped, and released. Sex was determined from observation of body morphology, and from the presence of stripped eggs or milt. Tagging was accomplished with either individually numbered metal jaw tags or Floy FT-4 spaghetti tags. Jaw tags were attached to the lower jaw of each fish. Spaghetti tags were inserted between the bones of the lower jaw and knotted. A combination of adipose, pectoral, and pelvic fin clips were used to monitor tag loss and to identify the location and period of capture of those fish loosing tags.

To facilitate testing of assumptions necessary for abundance estimation, each reach of river under investigation was divided into three equal-length river sections. In the Chena River, the reach under investigation was bounded upstream by the first bridge crossing on the Chena Hot Springs Road (river kilometer 145) and bounded downstream by the Moose Creek dam complex (river kilometer 72; Figure 1). In the Salcha River, the reach under investigation was bounded upstream by the confluence with Caribou Creek (river kilometer 97) and bounded downstream by the confluence with the Tanana River (river kilometer 0; Figure 2). Although untested, these river reaches were assumed

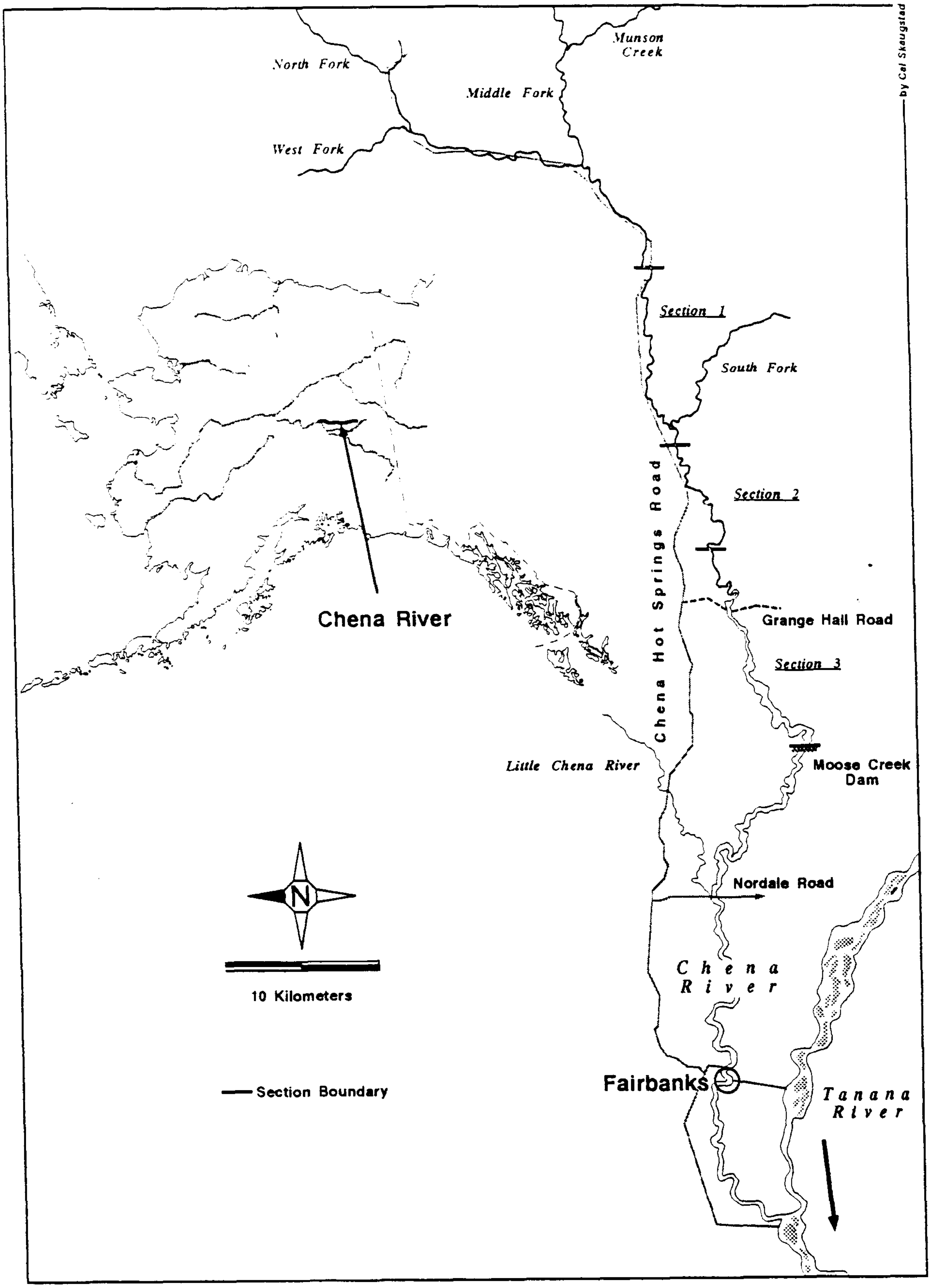

Figure 1. The Chena River drainage with three river sections delineated.

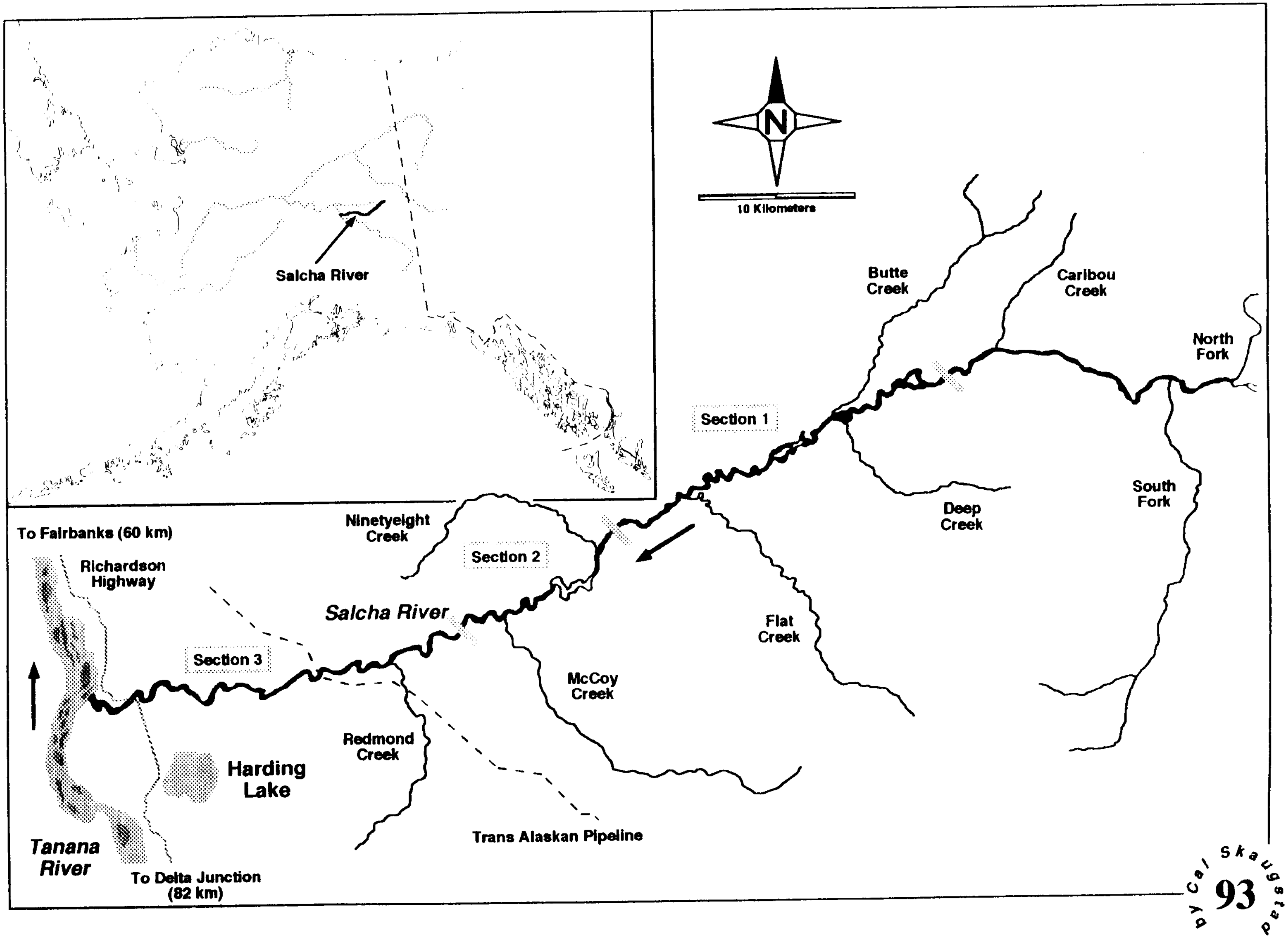

Figure 2. The Salcha River drainage with three river sections delineated.

to encompass most of the respective spawning areas for chum salmon and are the areas aerially surveyed by Commercial Fisheries Division. All sampling was performed between 5 and 21 August, with two complete passes through the Chena River reach, and one partial and two complete passes through the Salcha River reach.

Recovery

Chum salmon carcasses were collected and examined for tags in each of the river sections where tagged chum salmon were released. Using a river boat, which was drifted in a downstream direction, carcasses were collected with long-handled spears. In sloughs, foot surveys were employed to collect carcasses. Carcasses were measured for length (ME-FK), sexed, and examined for a tag and for fin clips. A sample of three to five vertebrae were removed from each fish. Vertebrae samples were cleaned by scraping away muscle tissue, separating the centra, and drying the centra in plastic ice cube trays. Ages were determined from readings of the centra with the aid of a compound microscope (1X to 4X magnification).

Abundance Estimation

Abundance was estimated with the modified Petersen estimator of Bailey (1951, 1952), as described by Seber (1982):

$$\hat{N} = \frac{n_1 (n_2 + 1)}{(m_2 + 1)}; \text{ and,} \qquad (1)$$

$$\hat{V}[\hat{N}] = \frac{n_1^2 (n_2 + 1) (n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)} \qquad (2)$$

where:

$\hat{N}$ = estimated abundance of chum salmon;
n_1 = number of chum salmon marked and released during marking;
n_2 = number of chum salmon captured during recovery;
m_2 = number of chum salmon examined with marks during recovery; and,
$\hat{V}[\hat{N}]$ = estimated variance of the abundance estimate.

Because of significant differences in recapture rates between river sections, this estimator was used to separately estimate abundance in each of two (Chena River) or three (Salcha River) river sections (Appendix A1). The resulting estimates of abundance and variance were then summed to estimate abundance and variance in the entire reach of each river. In addition, each data set was examined for potential bias due to sex-specific, length-specific, and time-specific differences in recovery rates. Section-specific, sex-specific, and time-specific differences were examined with chi-square tests of independence, while length-specific differences were examined with a two-sample Kolmogorov-Smirnov test (Zar 1984). Probabilities of a Type I error (α) of 0.05 or less were considered significant. Mixing of marked fish between river sections was assessed by examination of capture histories of recaptured fish (Appendix A1).

Equations 1 and 2 were used to estimate abundance and variance in each river section, with one exception. In the lower river section of the Chena River, an unknown number of marked fish migrated upstream between marking and recovery. Since low numbers of fish were marked and released during marking, only one (1) recapture was observed during recovery efforts in the lower section. To estimate the number of marked chum salmon remaining in the lower river section during recovery, the Darroch (1961) estimator for the marked-to-recaptured ratio was used (from Seber 1982):

$$\hat{\rho} = M^{-1}a \tag{3}$$

where:

$\hat{\rho}$ = an array of the marked-to-recaptured ratio in each river section;
M = a matrix of recaptures arranged by river section of marking (row elements) and by river section of recapture (column elements); and,
a = an array of fish marked and released by river section.

The element in the ρ array that corresponds to the lower river section (ρ_1) can be considered an estimate of the number of marks remaining in the lower section during recovery, only if the number of recaptures is one. Variance of ρ_1 is approximately ρ_1^2 (if recaptures = 1; Seber 1982)[1], similar to the use of n_1^2 in equation 2. Equations 1 and 2 would then reevaluate to:

$$\hat{N}' = \frac{\hat{\rho}_1 (n_2 + 1)}{(m_2 + 1)}\text{; and,} \tag{4}$$

$$\hat{V}[\hat{N}'] = \frac{\hat{\rho}_1^2 (n_2 + 1)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)} \tag{5}$$

In this way, an estimate of abundance in the lower section of the Chena River could be calculated without introducing bias in estimation of abundance in the middle and upper river sections. Chum salmon marked and released in the lower section and later recaptured in the upper or middle sections were considered unmarked fish in these sections.

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[1] From Seber (1982, page 433), the variance-covariance matrix (Σ) of the array ρ is estimated with:

$$E[(\hat{\rho}-\rho)(\hat{\rho}-\rho)'] = \sum \approx D_\rho \Theta^{-1} D_\mu D_\alpha^{-1} \Theta'^{-1} D_\rho$$

where: D_ρ is a diagonal matrix of the array ρ;
Θ is a matrix of the estimated probabilities of movement between river sections;
D_μ is a diagonal matrix with elements $\mu_i = (\Sigma\ \theta_{ij}/p_j) - 1$; and,
D_α is a diagonal matrix of marked fish in each section.

The diagonal elements of $\sum$ are the variances of the elements of the array ρ.

Statistical bias of each estimate of abundance was evaluated with bootstrap methods as detailed by Bernard and Hansen (1992).

Age, Size, and Sex Compositions

Although abundance estimates were stratified by river section, no differences in age, size, and sex compositions between river sections were found. Therefore, age, size, and sex compositions were estimated directly from data collected during the recovery (carcass survey). Vertebrae were collected from chum salmon carcasses examined on the Salcha River however, these samples were not aged.

All estimates of proportions and associated variance were calculated similarly, using the general formulae:

$$\hat{p}_z = n_z/n; \text{ and,} \tag{6}$$

$$\hat{V}(\hat{p}_z) = \hat{p}_z(1-\hat{p}_z)/(n-1) \tag{7}$$

where:

$\hat{p}_z$ = the estimated proportion (by sex, age, or length) of chum salmon in category z;

n_z = the number of chum salmon in category z; and,

n = the total number of chum salmon in the sample.

The abundance of each sex-age group was estimated using:

$$\hat{N}_{sa} = (\hat{p}_a)(\hat{p}_s)(\hat{N}) \tag{8}$$

The variance was estimated using (Goodman 1960):

$$\hat{V}(\hat{N}_{sa}) = \hat{N}^2\hat{p}_s^2\hat{V}(\hat{p}_a) + \hat{N}^2\hat{p}_a^2\hat{V}(\hat{p}_s) + \hat{p}_s^2\hat{p}_a^2\hat{V}(\hat{N}) - \hat{N}^2\hat{V}(\hat{p}_s)\hat{V}(\hat{p}_a) - \hat{p}_s^2\hat{V}(\hat{N})\hat{V}(\hat{p}_a) - \hat{p}_a^2\hat{V}(\hat{N})\hat{V}(\hat{p}_s) + \hat{V}(\hat{N})\hat{V}(\hat{p}_s)\hat{V}(\hat{p}_a) \tag{9}$$

where:

$\hat{N}$ = the estimated abundance for all chum salmon

$\hat{V}(\hat{N})$ = the variance of abundance

$\hat{p}_s$ = the estimated proportion of chum salmon of sex s;

$\hat{V}(\hat{p}_s)$ = the variance of the estimated proportion of chum salmon of sex s;

$\hat{p}_a$ = the estimated proportion of chum salmon of age a; and,

$\hat{V}(\hat{p}_a)$ = the variance of the estimated proportion of chum salmon of age a.

Estimates of mean length-at-age were generated with standard normal procedures. Simple averages and squared deviations from the mean were used to calculate means and variances of the means.

RESULTS

Chena River

A total of 424 chum salmon were marked and released during 5 through 14 August (Table 1). During recovery (11 through 20 August), 490 carcasses were examined and 48 were recaptures. No tag losses were observed.

Tests of Assumptions:

Using data from all three river sections, there was a significant difference in recovery rates of male and female chum salmon ($\chi^2 = 3.76$, df = 1, $P \approx 0.05$; Table 2). However, there was no significant difference in the size distributions of fish marked and fish recaptured ($D = 0.10$, $P \approx 0.79$; Figure 3A). No significant difference was found between recovery rates of fish marked during the first electrofishing pass and fish marked during the second electrofishing pass ($\chi^2 = 0.50$, df = 1, $P \approx 0.48$; Table 3). Recapture rates of chum salmon differed significantly between river sections ($\chi^2 = 16.10$, df = 2, $P \approx 3.19 \times 10^{-4}$). In particular, recapture rate was lowest in the lower section and highest in the upper section (Table 4). There was no significant difference in recapture rates of the upper and middle sections ($\chi^2 = 3.05$, df = 1, $P \approx 0.08$). Inspection of the recapture data for mixing revealed one fish that was marked in the lower section had migrated upstream to the upper section (Table 4).

Based on these tests the following inferences were made:

1) differences in recovery rates between sexes of chum salmon were not due to differences in size distributions between sexes;

2) time of marking (pass 1 versus pass 2) did not affect recovery rate;

3) extreme differences in recapture rates between river sections necessitated the use of separate estimation techniques for the lower river section;

4) mixing occurred, but the data were insufficient to conclude that mixing was complete; and,

5) low recapture rate in the lower section could potentially bias estimates of abundance in the middle and upper sections if data from the lower section were combined with one or both of the other sections.

Table 1. Catches of chum salmon by day and by sampling area for electrofishing and carcass surveys conducted on the Chena River during 1992.

River Section	Marking Event (Electrofishing)			Recapture Event (Carcass Survey)		
	Pass 1	Pass 2	Total	Pass 1	Pass 2	Total
Upper						
Date	Aug 6	Aug 11-12		Aug 11-12	Aug 17-18	
Males	75	53	128	39	47	86
Females	69	64	133	35	80	115
Total	145	117	262	74	127	201
Middle						
Date	Aug 7	Aug 12-13		Aug 12-13	Aug 18-19	
Males	22	20	42	60	23	83
Females	31	23	54	75	23	98
Total	53	43	96	135	46	181
Lower						
Date	Aug 5	Aug 14		Aug 14	Aug 19-20	
Males	0	18	18	33	17	50
Females	26	22	48	32	26	58
Total	26	40	66	65	43	108
All Sections						
Date	Aug 5-7	Aug 11-14		Aug 11-14	Aug 17-20	
Males	97	91	188	132	87	219
Females	126	109	235	142	129	271
Total	224	200	424	274	216	490

Table 2. Number of male and female chum salmon marked while electrofishing that were recovered and not recovered during carcass sampling, Chena River, 1992.

	Males	Females	Total
Recovered	15	33	48
Not Recovered	173	203	376
Total Released	188	236	424
Recovery Rate	0.08	0.14	0.11

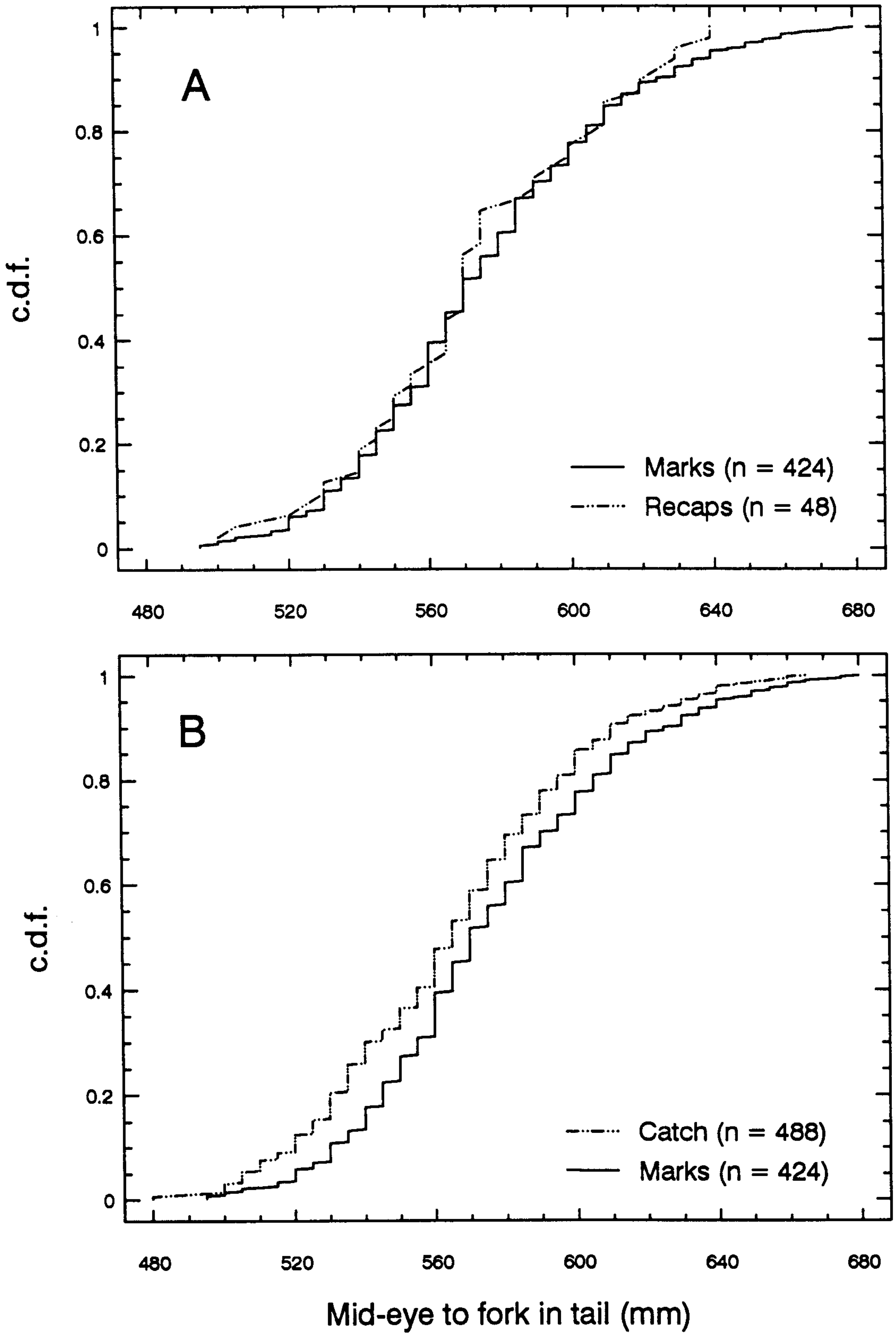

Figure 3. Cumulative distribution functions (c.d.f.) of lengths of chum salmon marked versus those recaptured (A) and lengths of chum salmon marked versus those examined for marks (B) in the Chena River.

Table 3. Number of chum salmon marked during the first or second electrofishing pass that were recovered and not recovered during carcass sampling, Chena River, 1992.

	Pass 1	Pass 2	Total
Recovered	23	25	48
Not Recovered	200	176	376
Total Released	223	201	424
Recovery Rate	0.10	0.12	0.11

Table 4. Capture and recapture history of all chum salmon captured during the mark-recapture experiment, Chena River, 1992.

River Section Where Marks Were Released	River Section Where Marks Were Recaptured				Number Marked	Number Not Recaptured
	Upper	Middle	Lower	Total		
Upper	30	6	0	36	256	220
Middle	0	10	0	10	102	92
Lower	1[a]	0	1	2	66	64
Total	31	16	1	48	424	376
Unmarked Carcasses	175	159	107	441	Total Number of Unique Fish Examined	
Total Carcasses	206	175	108	489	865	

[a] This recapture was treated as an unmarked fish for the estimate of abundance in the upper and middle sections.

Abundance Estimate:

Abundance of chum salmon in the Chena River during the recovery event was 6,083 fish (SE = 1,857 fish). Using data from the upper and middle sections only, abundance of male and female chum salmon was 1,806 fish and 1,251 fish, respectively. The sum of these estimates (3,057 fish, SE = 463) was not different from the estimate with sexes combined (2,910 fish, SE = 393; Table 5), so the combined estimate was used. Statistical bias of this estimate was 2.0% (Table 5).

Based on the probability of movement from the lower section to the upper section, 58 (SE = 58) of 66 fish marked in the lower section remained in the lower section during recovery. Abundance of chum salmon in the lower section during the recovery event was 3,173 fish (SE = 1,815 fish; Table 5). Low recapture rate caused considerable statistical bias in this estimate (bias = 21.1%). Overall statistical bias of the summed estimate was 12.0%.

An aerial survey of the Chena River to count chum salmon gave a peak count of 848 fish (R. Holder, Alaska Department of Fish and Game, Fairbanks, personal communication) or 13.9% (SE = 4.2%) of the estimated abundance.

Age, Size, and Sex Compositions:

There was a significant difference in the size distributions of fish marked and fish recovered ($D = 0.17$, $P \approx 4.60 \times 10^{-6}$; Figure 3B). Therefore age, size, and sex information was taken from the recovery data set. There was no significant differences in age composition ($\chi^2 = 4.91$, df = 4, $P \approx 0.30$) and sex composition ($\chi^2 = 0.37$, df = 2, $P \approx 0.83$) between river sections, so no adjustments were needed to weight for abundance in each river section.

Age composition was composed of predominantly age 0.4 fish, regardless of sex (Table 6). Age 0.5 fish were slightly more abundant than age 0.3 fish, but these two ages accounted for less than 35% of abundance of either sex. Female chum salmon were predominantly 500 to 599 mm in length, while males were predominantly 550 to 649 mm in length (Table 7). These differences were seen in length-at-age, with age 0.4 females averaging 550 mm and age 0.4 males averaging 580 mm (Table 8). Abundance of female chum salmon was 3,359 fish (SE = 1,034 fish). Abundance of male chum salmon was 2,724 fish (SE = 842 fish; Table 6).

Salcha River

A total of 747 chum salmon were marked and released during 5 through 16 August (Table 9). During recovery (18 through 21 August), 1,136 carcasses were examined and 92 were recaptures. No tag losses were observed.

Tests of Assumptions:

Using data from all three river sections, there was no significant difference in recovery rates of male and female chum salmon ($\chi^2 = 1.81$, df = 1, $P \approx 0.18$; Table 10). In addition, there was no significant difference in the size distributions of fish marked and fish recaptured ($D = 0.08$, $P \approx 0.63$; Figure 4A). No significant difference was found between recovery rates of

Table 5. Estimates of abundance and standard error of chum salmon in two sections of the Chena River, 1992.

Section	n_1	n_2	m_2	N	SE	CV(%)	Bias(%)
Upper & Middle	358	381	46	2,910	393	13.5	2.0
Lower	66(58)[a]	108	1	3,173	1,815	57.2	21.1
Totals	424	489	47	6,083	1,857	30.5	12.0

[a] Number in parentheses is the estimated number of marks in the lower section during the second event. This estimate of n_1 was used to estimate abundance in the lower section during the second event (variance of n_1 is approximately n_1^2 in this case).

Table 6. Estimates of proportions and abundance of female and male chum salmon by age class collected during carcass sampling on the Chena River, 1992.

	Brood Year and Age Group			
	1988	1987	1986	
	0.3	0.4	0.5	Total
Females				
Sample Size	30	169	36	235[a]
Proportion of Females in Sample				0.55
Standard Error				0.02
Proportion of Females at age in sample	0.13	0.72	0.15	
Standard Error	0.02	0.03	0.02	
Abundance	429	2,416	515	3,359
Standard Error	149	750	175	1,034
Males				
Sample Size	27	135	40	202[a]
Proportion of Males in Sample				0.45
Standard Error				0.02
Proportion of Males at age in sample	0.13	0.67	0.20	
Standard Error	0.02	0.03	0.03	
Abundance	364	1,820	539	2,724
Standard Error	129	569	182	842
Total				
Sample Size	57	304	76	437
Proportion at age in Sample	0.13	0.70	0.17	
Standard Error	0.02	0.02	0.02	
Abundance	793	4,236	1,054	
Standard Error	260	1,298	340	

[a] Thirty five females (of 270 fish total) and 17 males (of 219 fish total) were not aged.

Table 7. Length compositions of female and male chum salmon carcasses sampled in the Chena River, 1992.

Length Category	Sample Size	Proportion of Sample	Standard Error
Female:			
<450	0	0	0
450-499	4	0.008	0.004
500-549	129	0.264	0.020
550-599	120	0.246	0.020
600-649	16	0.033	0.008
650+	0	0	0
Totals:	269	0.551	0.023
Male:			
<450	0	0	0
450-499	2	0.004	0.003
500-549	23	0.047	0.010
550-599	116	0.238	0.019
600-649	70	0.143	0.016
650+	8	0.016	0.006
Totals:	219	0.449	0.023
Female and Male:			
<450	0	0	0
450-499	6	0.012	0.005
500-549	152	0.311	0.021
550-599	236	0.484	0.023
600-649	86	0.176	0.017
650+	8	0.016	0.006
Totals:	488	1.000	0

Table 8. Estimated length-at-age of Chena River chum salmon, 1992.

Ocean Age	Sample Size	Length (mm) Mean	SE	Range
Females:				
3	30	530	5	480 - 590
4	169	550	2	480 - 635
5	36	560	5	505 - 615
Total	235	550	2	480 - 635
Males:				
3	27	565	6	500 - 640
4	135	580	3	485 - 665
5	40	610	4	560 - 655
Total	202	585	2	485 - 665
Females and Males:				
3	57	545	5	480 - 640
4	304	565	2	480 - 665
5	76	585	4	505 - 655
Total	437	565	2	480 - 665

Table 9. Catches of chum salmon by day and by sampling area for electrofishing and carcass surveys conducted on the Salcha River during 1992.

River Section	Marking Event (Electrofishing)				Recapture (Carcass Survey)
	Pass 1	Pass 2	Pass 3	Total	Pass 4
Upper					
Date		Aug 10-12	Aug 14		Aug 18-19
Males	0	183	79	262	238
Females	0	133	72	205	295
Total	0	316	151	467	798
Middle					
Date	Aug 5	Aug 13	Aug 15		Aug 20
Males	9	42	23	74	78
Females	3	33	42	78	82
Total	12	75	66	153	160
Lower					
Date	Aug 5	Aug 13	Aug 16		Aug 20-21
Males	2	14	37	53	67
Females	1	17	55	73	111
Total	4	31	92	127	178
All Sections					
Date	Aug 5	Aug 10-13	Aug 14-16		Aug 18-21
Males	11	239	139	389	383
Females	4	183	169	356	488
Total	16	422	309	747	1,136

Table 10. Number of male and female chum salmon marked while electrofishing that were recovered and not recovered during carcass sampling, Salcha River, 1992.

	Males	Females	Total
Recovered	42	50	92
Not Recovered	347	306	653
Total Released	389	356	745
Recovery Rate	0.11	0.14	0.11

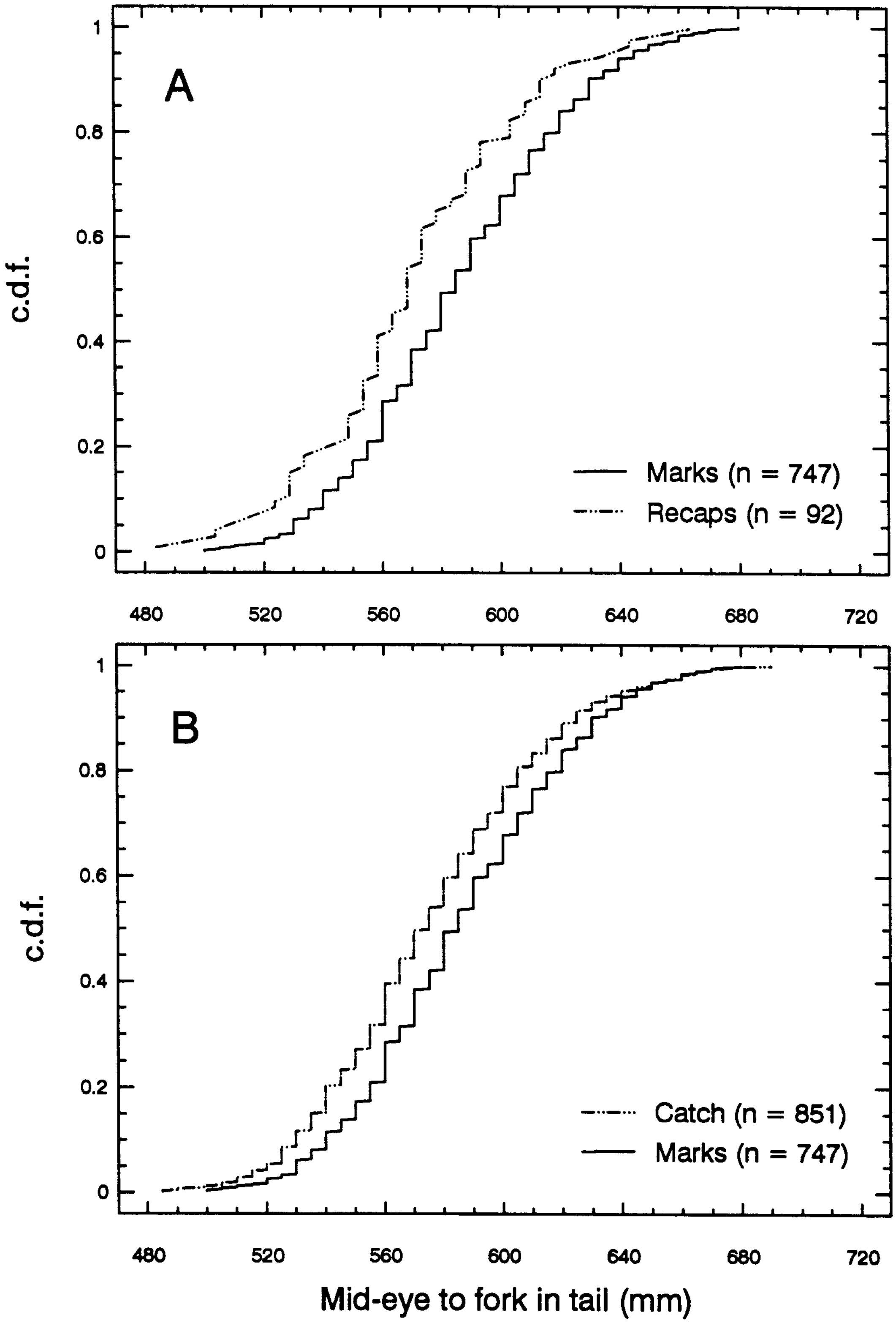

Figure 4. Cumulative distribution functions (c.d.f.) of lengths of chum salmon marked versus those recaptured (A) and lengths of chum salmon marked versus those examined for marks (B) in the Salcha River.

fish marked during the first and second electrofishing passes, and fish marked during the third electrofishing pass ($\chi^2 = 2.46$, df = 1, P ≈ 0.12; Table 11). Recapture rates of chum salmon differed significantly between river sections ($\chi^2 = 18.69$, df = 2, P ≈ 8.70×10^{-5}). In particular, recapture rate was lowest in the lower section and highest in the middle section (Table 12). The upper and middle sections could not be combined as was done for the Chena River data set ($\chi^2 = 4.28$, df = 1, P ≈ 0.04). Inspection of the recapture data for mixing revealed one fish that was marked in the middle section had migrated upstream to the upper section (Table 12).

Based on these tests the following inferences were made:

1) there were no differences in recovery rate by sex or size;

2) time of marking (pass 1&2 versus pass 3) did not affect recovery rate;

3) differences in recapture rates between river sections necessitated the use of separate estimation techniques for each river section;

4) mixing between river sections probably did not occur; and,

5) low recapture rate in the lower section could potentially bias estimates of abundance in the middle and upper sections if data from the lower section were combined with one or both of the other sections.

Abundance Estimate:

Abundance of chum salmon in the Salcha River during the recovery event was 14,057 fish (SE = 3,813 fish). Separate abundance estimates were 5,408 fish, 1,071 fish, and 7,578 fish for the upper, middle, and lower sections, respectively (Table 13). Statistical bias of these estimates ranged from 1.0% for the upper section to 25.9% for the lower section. Overall statistical bias was 16.3%. Assuming recovery rates had been similar between sections, abundance would have been 9,133 fish (SE = 903 fish), much lower than the summed estimate.

An aerial survey of the Salcha River to count chum salmon gave a peak count of 3,222 fish (R. Holder, Alaska Department of Fish and Game, Fairbanks, personal communication) or 22.9% (SE = 6.2%) of the estimated abundance.

Size and Sex Compositions:

There was a significant difference in the size distributions of fish marked and fish recovered (D = 0.19, $P < 0.01$; Figure 4B). Therefore size and sex information was taken from the recovery data set. There was no significant difference in sex composition ($\chi^2 = 4.48$, df = 2, P ≈ 0.11) between river sections, so no adjustments were needed to weight for abundance in each river section.

Female chum salmon were predominantly 500 to 599 mm in length, while males were predominantly 550 to 649 mm in length (Table 14). There were 56.5% (SE = 1.7%) females and 43.5% males (SE = 1.7%) in the Salcha River during the

Table 11. Number of chum salmon marked during the first and second or third electrofishing pass that were recovered and not recovered during carcass sampling, Salcha River, 1992.

	Pass 1&2	Pass 3	Total
Recovered	47	45	92
Not Recovered	391	264	655
Total Released	438	309	747
Recovery Rate	0.11	0.15	0.12

Table 12. Capture and recapture history of all chum salmon captured during the mark-recapture experiment, Salcha River, 1992.

River Section Where Marks Were Released	River Section Where Marks Were Recaptured: Upper	Middle	Lower	Total	Number Marked	Number Not Recaptured
Upper	67	0	0	67	467	400
Middle	1	22	0	23	153	130
Lower	0	0	2	2	127	125
Total	68	22	2	92	747	655
Unmarked Carcasses	730	138	176	1,044	Total Number of Unique Fish Examined	
Total Carcasses	798	160	178	1,136	1,791	

Table 13. Estimates of abundance and standard error of chum salmon in three sections of the Salcha River, 1992.

Section	n_1	n_2	m_2	N	SE	CV(%)	Bias(%)
Upper	467	798	68	5,408	618	11.4	1.0
Middle	153	160	22	1,071	202	18.9	3.5
Lower	127	178	2	7,578	3,757	49.6	25.9
Totals	747	1,136	92	14,057	3,813	27.1	16.3

Table 14. Length compositions of female and male chum salmon carcasses sampled in the Salcha River, 1992.

Length Category	Sample Size	Proportion of Sample	Standard Error
Female:			
<450	0	0	0
450-499	7	0.008	0.003
500-549	171	0.201	0.014
550-599	257	0.302	0.016
600-649	45	0.053	0.008
650+	1	0.001	0.001
Totals:	481	0.565	0.017
Male:			
<450	0	0	0
450-499	0	0	0
500-549	20	0.024	0.005
550-599	158	0.186	0.013
600-649	159	0.187	0.013
650+	33	0.039	0.007
Totals:	370	0.435	0.017
Female and Male:			
<450	0	0	0
450-499	7	0.008	0.003
500-549	191	0.224	0.014
550-599	415	0.488	0.017
600-649	204	0.240	0.015
650+	34	0.040	0.007
Totals:	851	1.000	0

recovery event. Abundance of female chum salmon was 7,876 fish (SE = 2,148 fish). Abundance of male chum salmon was 6,181 fish (SE = 1,692 fish).

DISCUSSION

Use of mark-recapture techniques to estimate escapements of chum salmon in the Chena and Salcha rivers appears feasible. If, through improvements to the sampling design, recapture rates could be equalized between river sections, relatively precise (CV of 15% and less) estimates of escapement would result. This was not the case for either river in 1992. Both sets of mark-recapture data suffered from insufficient recaptures and low recapture rate in the lower sections of each river. Data were not recorded by river mile or some other small section of river, so section boundaries could not be altered to allow for additional recaptures in the lower section. Recording of mark-recapture data in units smaller than the section may facilitate abundance estimation in future years. Mark-recapture data from each river section could also have been combined, ignoring differences in recapture rate. In the Chena River analysis, the middle and lower sections could have been combined; this might have increased precision (potential CV of 21.1% versus actual CV of 30.5%), but might have biased the estimate of abundance (5,329 fish versus 6,083 fish). The same logic could have been applied to the Salcha River data set, with similar results (9,205 fish with a CV of 10.3% versus 14,057 fish with a CV of 27.1%). Bias in these situations would not result from a poor fit to the estimation model, but inaccuracy due to failure of the assumptions. In an attempt to provide the most accurate (less failures of assumptions) estimate of escapement to managers, precision of the estimate was sacrificed. As a result, these are probably worst case scenarios of potential precision in the future. In all likelihood, precision of estimates of chum salmon escapement could approach those of chinook salmon estimates in these same rivers.

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APPENDIX A

Appendix A1. Statistical tests for analyzing data from a mark-recapture experiment for gear bias, and for evaluating the assumptions of a two-event mark-recapture experiment.

The following statistical tests will be used to analyze the data for significant bias due to gear selectivity by sex and length:

1. A test for significant gear bias by sex will be based on a contingency table of the number of males and females that were recaptured and were not recaptured. The chi-square statistic will be used to evaluate the bias.

If Test 1 indicates a significant bias, the following tests will be done for males and females, separately. If Test 1 does not indicate a significant bias, males and females will be combined and the following tests will be done.

2. Tests for significant gear bias by size will be based on: (A) Kolmogorov-Smirnov goodness of fit test comparing the distributions of the lengths of all fish that were marked during electrofishing and all marked fish that were collected during the carcass survey; and, (B) Kolmogorov-Smirnov two sample test comparing the distributions of the lengths of all fish that were captured during electrofishing and all fish that were collected during the carcass survey. The null hypothesis is no difference between the distributions of lengths for Test A or for Test B.

For these two tests there are four possible outcomes:

Case I:

Accept $H_o(A)$ Accept $H_o(B)$

There is no size-selectivity during the first sampling event (when fish were marked) or during the second sampling event (when carcasses were collected).

Case II:

Accept $H_o(A)$ Reject $H_o(B)$

There is no size-selectivity during the second sampling event but there is size-selectivity during the first sampling event.

Case III:

Reject $H_o(A)$ Accept $H_o(B)$

There is size-selectivity during both sampling events.

Case IV:

Reject $H_o(A)$ Reject $H_o(B)$

There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.

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Depending on the outcome of the tests, the following procedures will be used to estimate the abundance of the population:

Case I: Calculate one unstratified estimate of abundance, and pool lengths, sexes, and ages from both sampling events to improve precision of proportions in estimates of compositions.

Case II: Calculate one unstratified estimate of abundance, and only use lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

Case III: Completely stratify both sampling events, and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Pool lengths, ages, and sexes from both sampling events to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data.

Case IV: Completely stratify both sampling events and estimate the abundance for each stratum. Add the estimates of abundance across strata to get a single estimate for the population. Also, calculate a single estimate of abundance without stratification.

Case IVa: If the stratified and unstratified estimates of abundance for the entire population are dissimilar, discard the unstratified estimate. Only use the lengths, ages, and sexes from the second sampling event to estimate proportions in composition, and apply formulae to correct for size bias (*See* Adjustments in Compositions for Gear Selectivity) to data from the second event.

Case IVb: If the stratified and unstratified estimates of abundance for the entire population are similar, discard the estimate with the larger variance. Only use the lengths, ages, and sexes from the first sampling event to estimate proportions in compositions, and do not apply formulae to correct for size bias.

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Closed Population

The following two assumptions must be fulfilled:

1. Catching and handling the fish does not affect the probability of recapture; and,

2. Marked fish do not lose their mark.

Catching and handling the fish should not affect the probability of recapture because the experiment is designed to mark live fish and later recover carcasses. If the jaw tag is lost, the fin clip given each fish will identify the river section where it was marked.

Of the following assumptions, only one must be fulfilled:

1. Every fish has an equal probability of being marked and released during electrofishing;

2. Every fish has an equal probability of being collected during the carcass survey; or,

3. Marked fish mix completely with unmarked fish between electrofishing and carcass surveys.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency table. The results will be used to determine the appropriate abundance estimator and if the estimate of abundance should be stratified by river section or period:

1. Null hypothesis is that marked-to-unmarked ratio is the same at all sites. Columns 1, 2, and 3 in the table will be the corresponding river section where the fish were recovered. Row 1 will be the number of marked fish collected during the carcass sampling event and row 2 will be the number of unmarked fish collected during the carcass sampling event. The column totals will be equal to the number of fish marked during the electrofishing event.

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If the test statistic is not significant, then either every fish had an equal probability of being marked (caught in the electrofishing gear) or marked fish mixed completely with unmarked fish between sampling events. In this case a Petersen estimate will be used to estimate abundance. If the test statistic is significant the following matrix will be created:

River Section of Release	River Section of Recapture		
	Lower	Middle	Upper
Lower			
Middle			
Upper			

If all the off-diagonal elements are zero, then a Petersen estimate will be calculated for each river section. The sum of the three estimates will be the overall abundance estimate. If the off-diagonal estimates are not zero, then Darroch's method will be used to estimate abundance. With these tests it is unknown whether the second assumption was fulfilled. Darroch's method will be used to insure an unbiased estimate.